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Surface topography of precursors Cu-Zn-Sn electrochemically deposited on Mo/glass and Mo-foil

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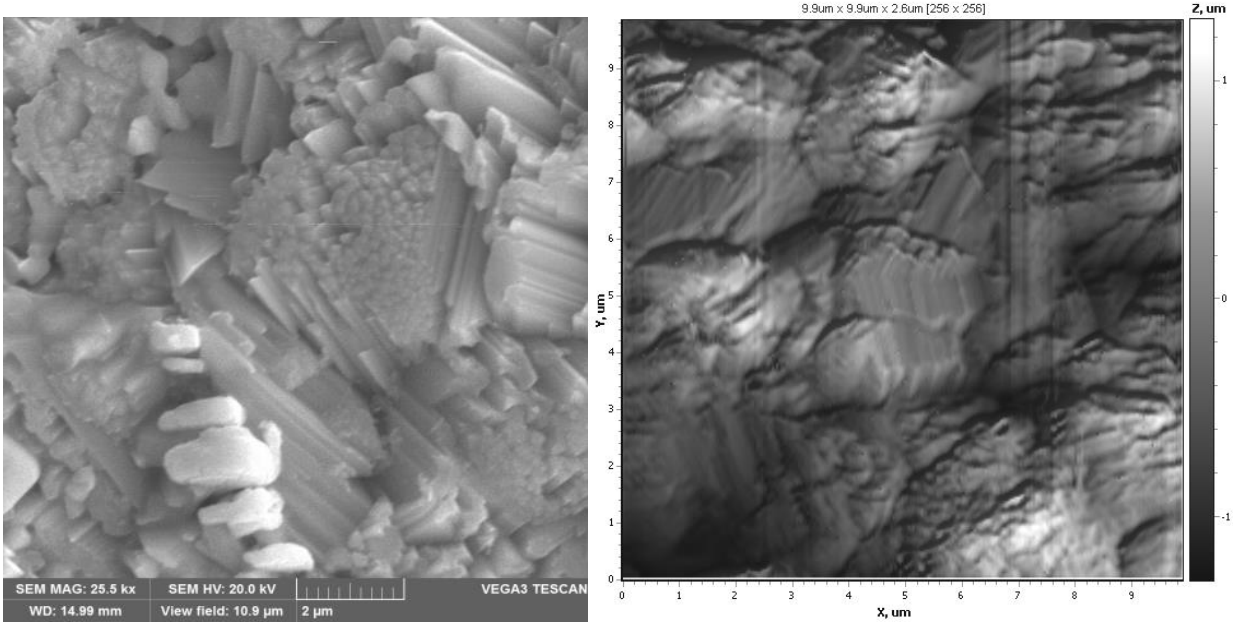
The paper discusses the possibility of constructing thin-film solar cells based on non-toxic and abundant $Cu_2ZnSnSe_4$ components (CZTSe) obtained by electrochemical deposition on Ta-foil substrates with subsequent selenization. Foil substrates open up new possibilities for application of flexible thin-film solar cells. Atomic force microscopy and scanning electron microscopy combined with energy dispersive spectrometry of secondary electrons were employed for the investigation of thin films topography.

Introduction: The semiconductor compound $Cu_2ZnSnSe_4$ (CZTSe) is a promising material for thin-film solar cells. Unlike the widely studied materials $CuIn_{1-x}Ga_xSe_2$ (CIGS) and CdTe, all CZTSe components are cheap and do not contain toxic cadmium [1-3]. The maximum achievable photoelectric conversion efficiency of solar cells on their basis is ~ 30% [4]. Studies on increasing the efficiency of photoconverters have shown that the surface of films and the morphology of interfaces characterized by roughness play an important role in improving the absorption of incident light onto the semiconductor layer by reducing reflection losses. A significant increase in the conversion efficiency by introducing the corresponding rough interfaces was reported in several papers [5,6].

Unlike glass substrates, metal foils have a coarser surface, which strongly affects the growth, crystal orientation, and other properties of subsequent layers. The rough surface of the layers in the solar cell directly affects its efficiency [7].

Results and discussion: AFM studies have shown (Fig. 1) that the surface of CZT precursors deposited on metal substrates has a similar microrelief and is different from the Mo/glass observed on the substrate [8,9].



(a) (b)

Figure 1. (a) SEM and (b) AFM images of the surface of Cu-Zn-Sn precursors on Ta-foil substrates.

The presence on the surface of CZTSe-produced coatings of complex micro-dimensional structures deposited on Ta-foils is confirmed by electron microscopy (Fig. 1a).

The surface of CZT precursors deposited on metal substrates is characterized by a complex structure (Fig. 1). When deposited on Ta-foil, a layered structure is observed on the surface, the thickness of the layers is 50-100 nm, the length of clusters formed is 2-4 μm, the transverse dimensions vary from 250 to 1000 nm in diameter, the layers have a common orientation within one cluster. Also, associations of layers in larger structures are observed, with the formation of depressions larger than in the case of previously studied Mo-foil materials. The resulting SEM images also confirm the formation of layered formations on the surface of CZT precursors on foil substrates. (Fig. 1a).

The "illumination" of the surface ends of layered structures on images obtained with the help of electron scanning microscopy may indicate the presence of metallic materials on the surface. In CZTSe films enriched in zinc, according to [10, 11], $Cu_2ZnSnSe_4$ crystals grow large and form a compact layer, leaving an excess of zinc on the surface and, as a result, lead to the formation of fine crystallites of Zinc selenide, which agrees well with the obtained AFM data for films CZTSe. The parameters of the topography of the original samples and samples after coating are presented in Table 1.

Table 1. parameters of the topography of the test samples.

Parameters	R_a, **нм**	R_q, **нм**
Substrate	68.66	88.48
Precipitated precursor CZT	225.48	282.81
Pre-annealed precursor CZT	31.60	40.50
CZTSe film	187.03	244.43

The roughness of the surfaces of precursor films deposited on substrates has a slight difference with a significant difference in the roughness of the substrates. The coating on the foil substrates, in comparison with the glass substrate with a sublayer of molybdenum, contributed to the elimination of defects in the form of scratches. Obviously, the roughness of the metal substrates exerts an insignificant influence on the parameters of the roughness of the coatings obtained, which agrees with the work [12, 13], which makes it possible to use them for thin-film photoconverters.

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